

Recent upgrades of the THEMIS solar telescope.



Laboratoire de Physique des Plasmas

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THEMIS Factsheet



Main French solar telescope

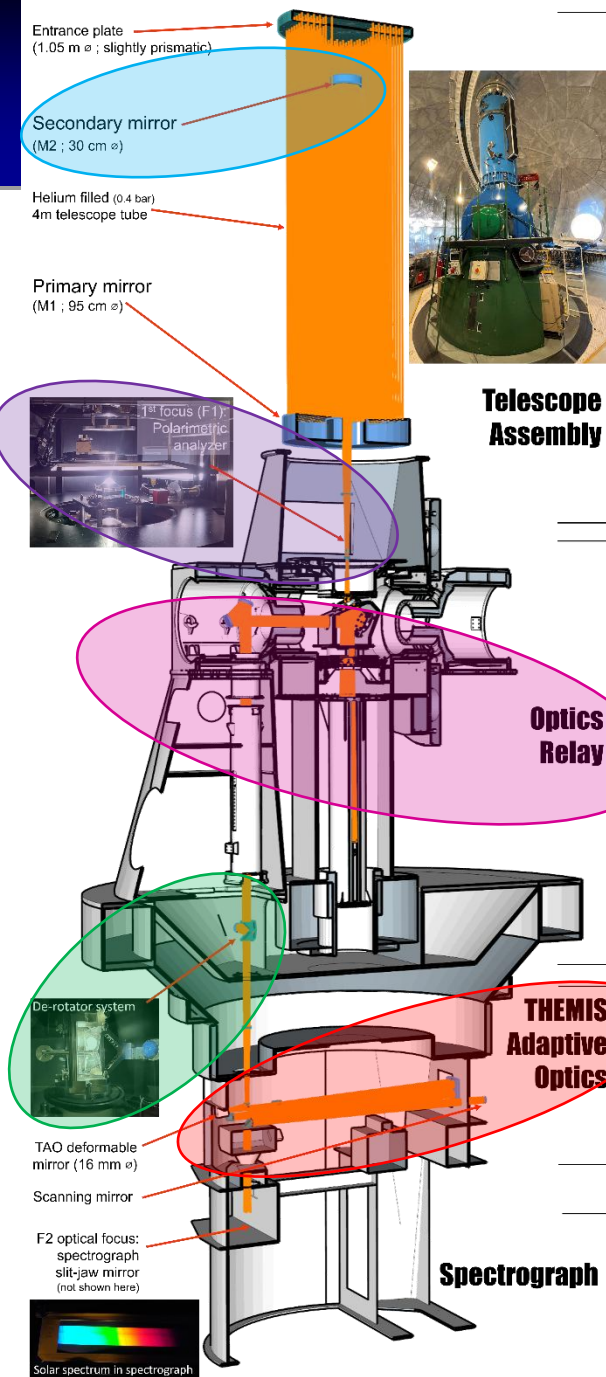
- Designed by J. Rayrole, P. Mein & M. Semel
- Located at Teide Observatory, Tenerife, Spain
- 1st light in March 1996, & commissioned in 1999



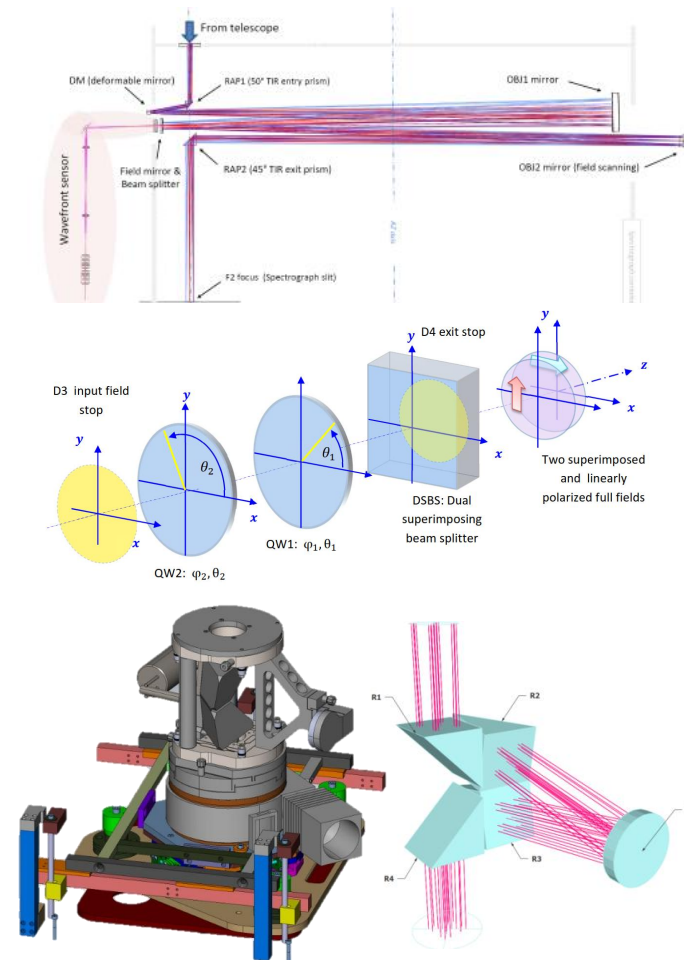
THEMIS @ OT in June 2025

- 1m-class solar telescope, with one the world “slowest” optical design:
 - Aperture: 92 cm ;
 - Effective focal length: 57m
 - Effective focal ratio: f/62
 - among world optically slowest inst.
 - 60”x60” or 120”x120” square field-of-view
- **MULTI Ray spectrograph (MTR2): ideal for high-spectral res. spectropolarimetry:**
 - Working spectral range: 4000 - 11000 Å
 - **Polarization calibration free**
 - **Ultra-high spectral resolving power:**
 - $R \sim 300\,000 - 400\,000$
 - **Simultaneous observations of user-defined set of up to 5 spectral ranges:**
 - $\sim 4-7\text{ Å}$ spectral range
 - $\sim 5-30\text{ mÅ}$ spectral resolution (0.3” slit)

"Total makeover" : 2016 → 2020



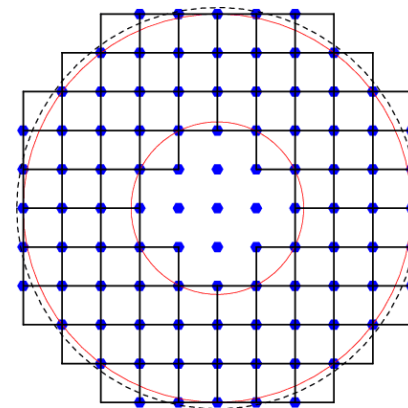
- **THEMIS has been widely renewed and redesigned**
 - Thanks to EU funding: ~1M€ from 2 IAC-led SOLARNET programs
- **M2 mirror re-aluminising** (WHT & THEMIS)
- **Themis Adaptive Optics:** “classical” single-DM adaptive optics based on innovative wavefront sensing and mirror commanding concepts (AIRI@CRAL & THEMIS)
- **Superimposed dual-beam polarimetric analysis** without field limitation (Semel M., Lopez A., Le Men C. & THEMIS)
- **“Polarization- friendly” complete redesign of the whole transfer optics (M3, M4 & M5)** (Le Men, C. & THEMIS)
- **New de-rotator system** (THEMIS)
- + new context, broadband and spectral cameras.



THEMIS Adaptive Optics (TAO)



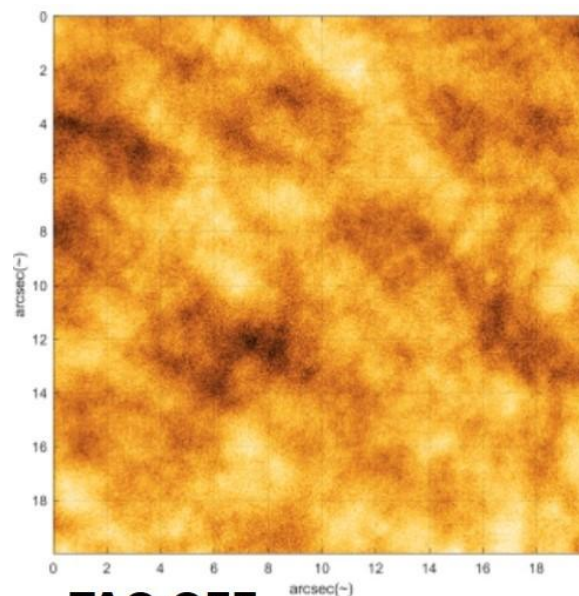
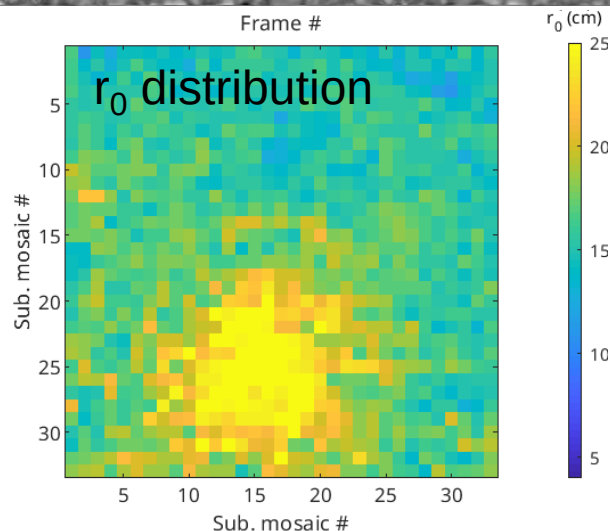
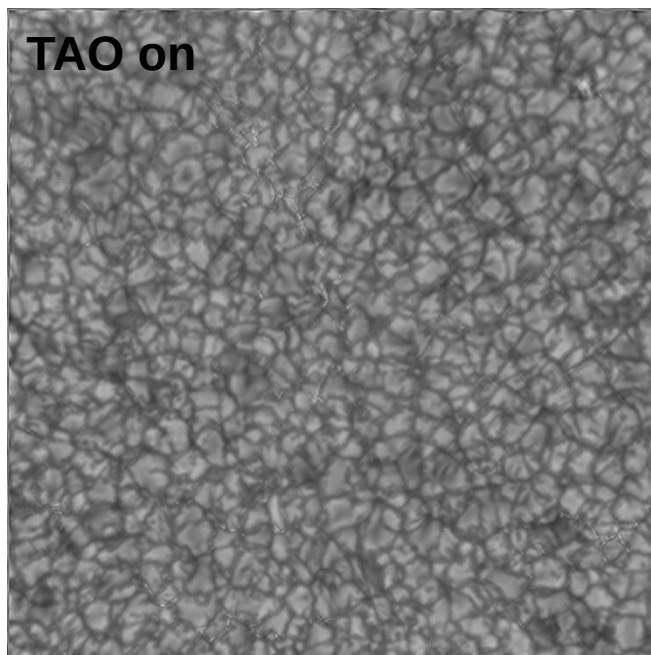
- **Challenging specification: compatible with THEMIS optical path (F1 polarisation analyser)**
- Started from scratch mid-2016
 - **Key role of AIRI team @ CRAL**
- Shack-Hartmann wavefront sensor: 76 sub-aperture
- 16mm deformable mirror (DM) with 97 actuators
- Efficient Real time correction (RTC)
 - CPU at 4.2 GHz, 4 cores, ~50 Gflops/core
 - Innovative DM control algorithms (Thiebaut et al. 22)
- Actual TAO characteristics:
 - ✓ **RTC software running in CPU @1250 Hz**
 - ✓ **Closed AO loop on the Sun in Dec. 2020**
 - ✓ **Effective whenever $r_0 > 3-4$ cm**
 - **Ongoing : unsupervised AO**
 - optimal correction whatever the conditions
 - provide inferred seeing conditions



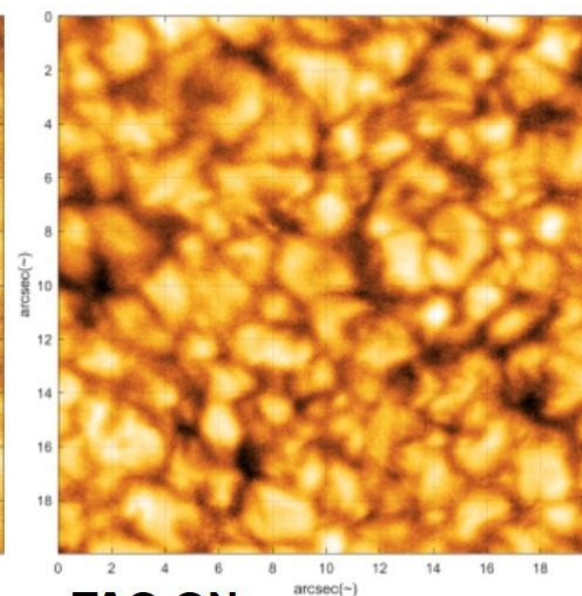
TAO geometry with a combination of DM/wavefront sensor set up in 'Fried configuration' with a spacing number of 10



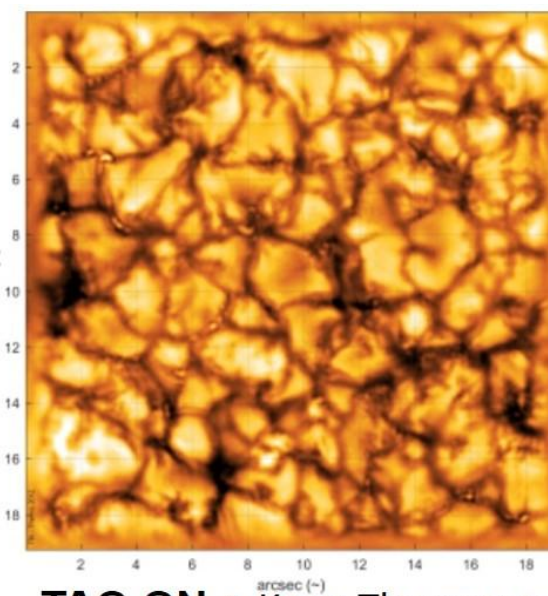
THEMIS Adaptive Optics (TAO): results on granulation



- seeing "daytime bad" : $r_0 \approx 3-4$ cm
- granulation contrast: 1.6 %



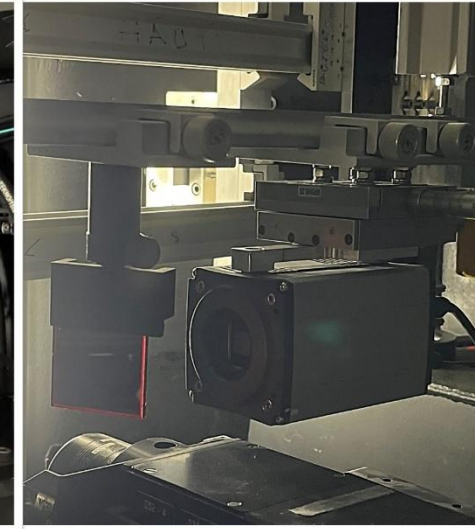
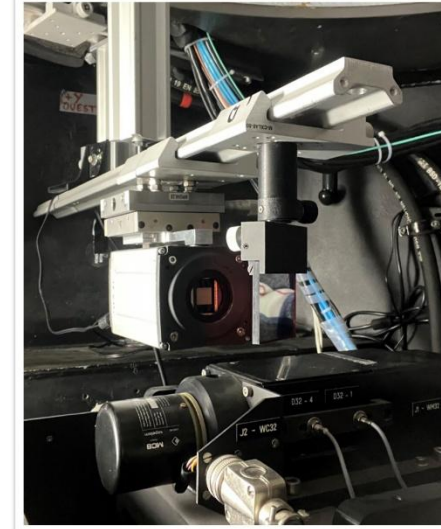
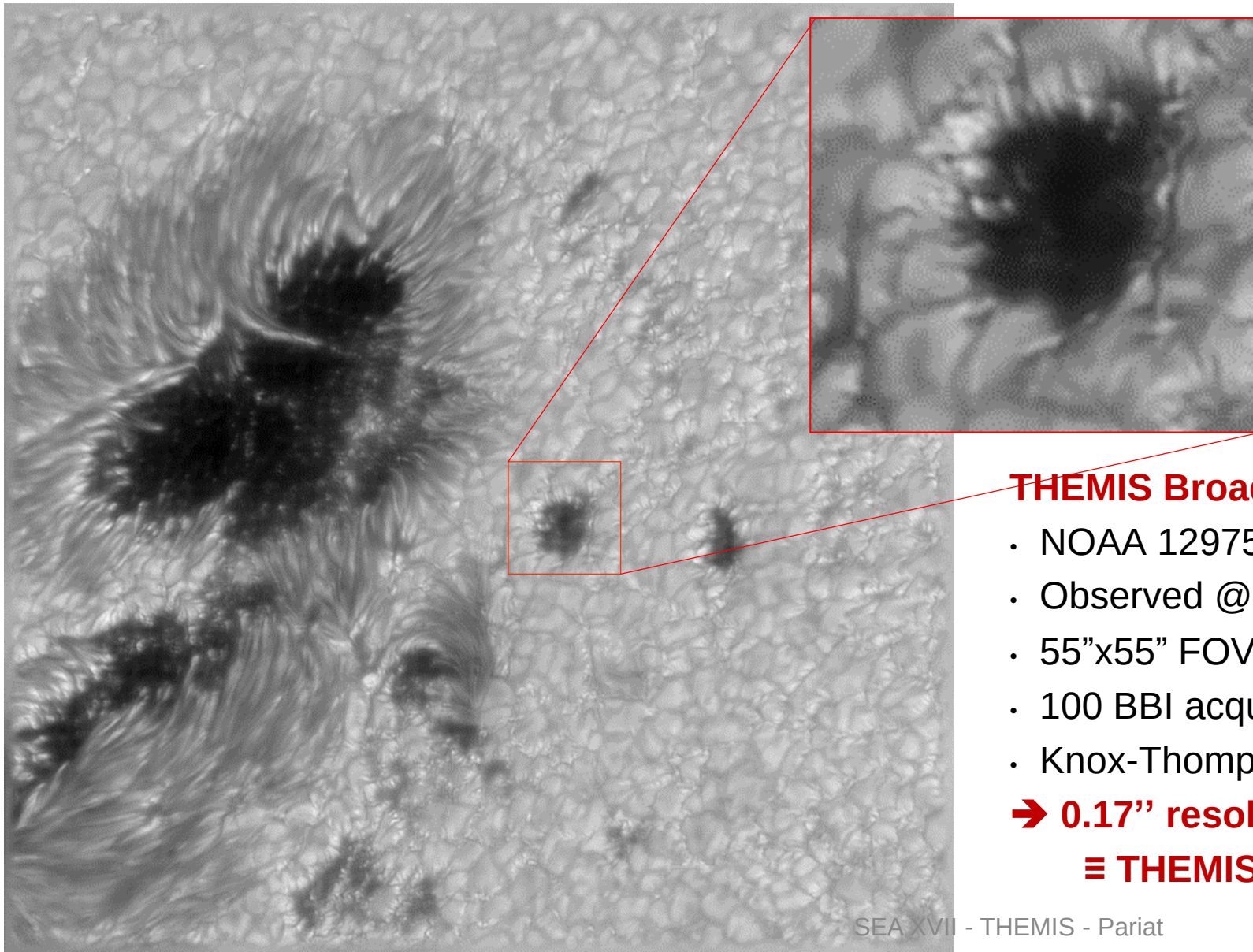
- seeing "daytime bad" : $r_0 \approx 3-4$ cm
- granulation contrast: 4.2 %



- granulation contrast: 9.6 %

- **TAO permits significant quantitative image quality gain:**
 - **in effective seeing:** Fried's coherence length from $r_0 \sim 7$ cm (ave. seeing)
 - ~ 25 cm at TAO focus
 - ~ 17 cm on rest of FOV, away from isoplanatic patch
 - **in granulation contrast:** from $\sim 1-2\%$ (bad seeing)
 - to $\sim 10\%$ (with image reconstruction)

THEMIS at diffraction limit: NOAA 12975



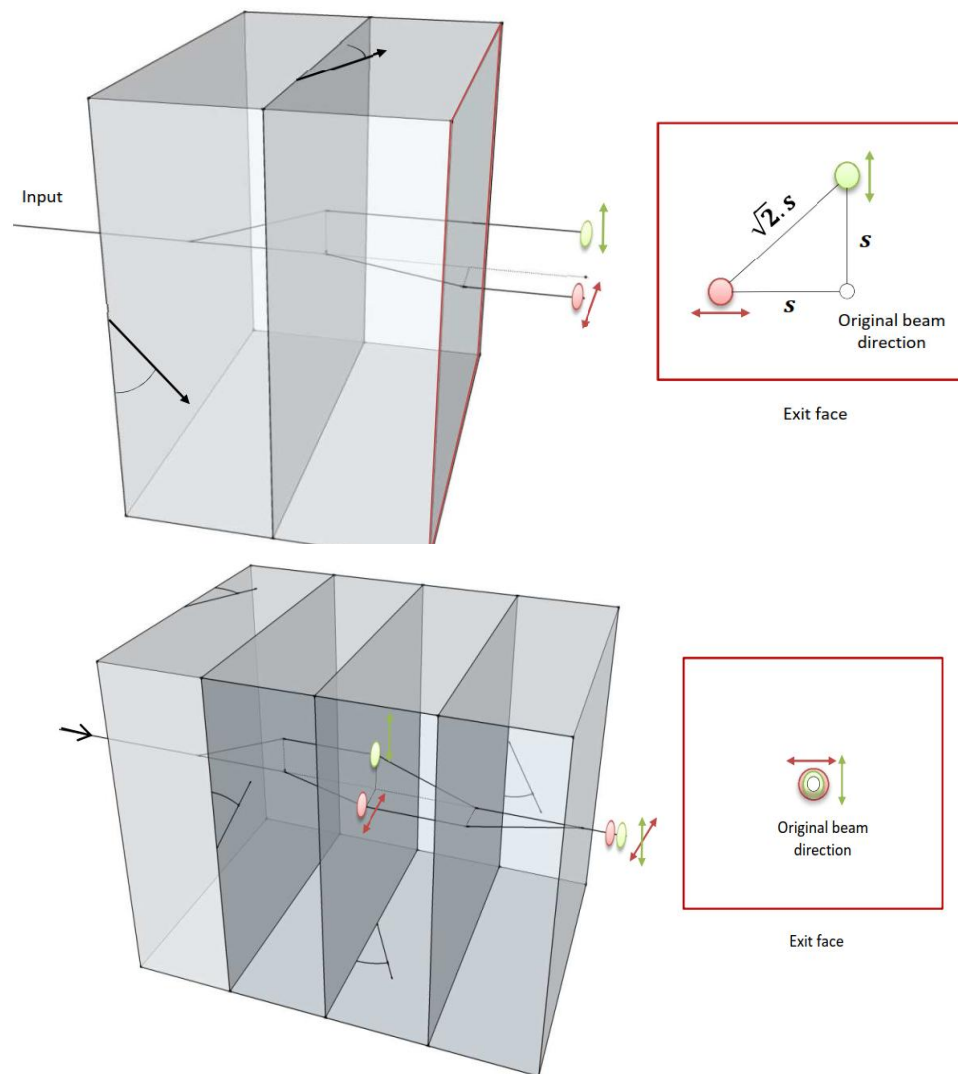
THEMIS Broadband Imaging (BBI)

- NOAA 12975 on 2022/03/31
- Observed @ $\sim 630\text{nm}$; 1nm broadband red filter
- 55"x55" FOV
- 100 BBI acquisition @ 40 images/s
- Knox-Thompson (speckle) image post-processing

➔ **0.17" resolution (0.035"/pixel)**

$\equiv$ THEMIS theoretical diffraction limit (@ $\sim 630\text{ nm}$)

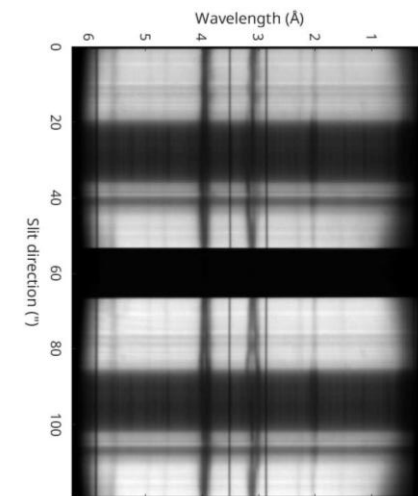
THEMIS polarization analysis



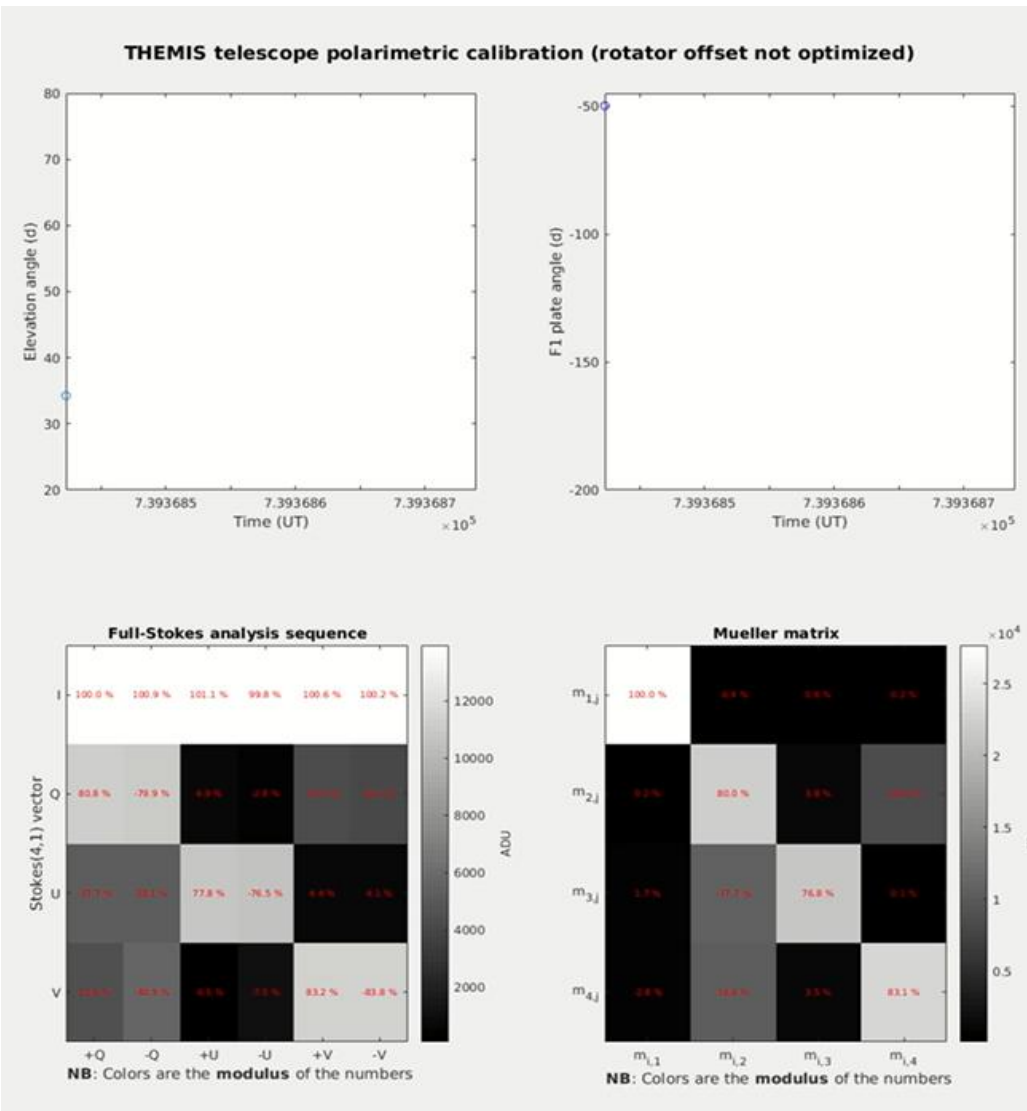
- New “polarization friendly”

- **AO-compatible optical path:**

- Polarization units + double Savart plates @ F1
→ **dual-beam with beam exchange.**
 - Wollaston prisms in front of spectral cameras:
→ complementary Stokes on camera FOV



THEMIS polarization analysis



• New “polarization friendly”

AO-compatible optical path:

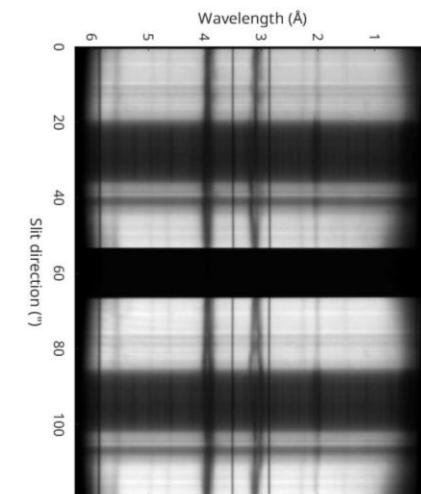
- Polarization units + double Savart plates @ F1
→ **dual-beam with beam exchange.**
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• THEMIS Mueller matrix:

$$M_{THEMIS} = \begin{pmatrix} 1.000 & -0.009 & -0.003 & 0.001 \\ -0.008 & 0.885 & 0.016 & -0.033 \\ 0.014 & -0.436 & 0.872 & 0.033 \\ -0.019 & 0.415 & 0.008 & 0.873 \end{pmatrix}$$

- Averaged over one full day
- Includes changing elevation axis and field derotation
- Quite constant along one day

• THEMIS remains a strongly polarization-calibration-free telescope, ideal for excellent spectropolarimetric measurements.

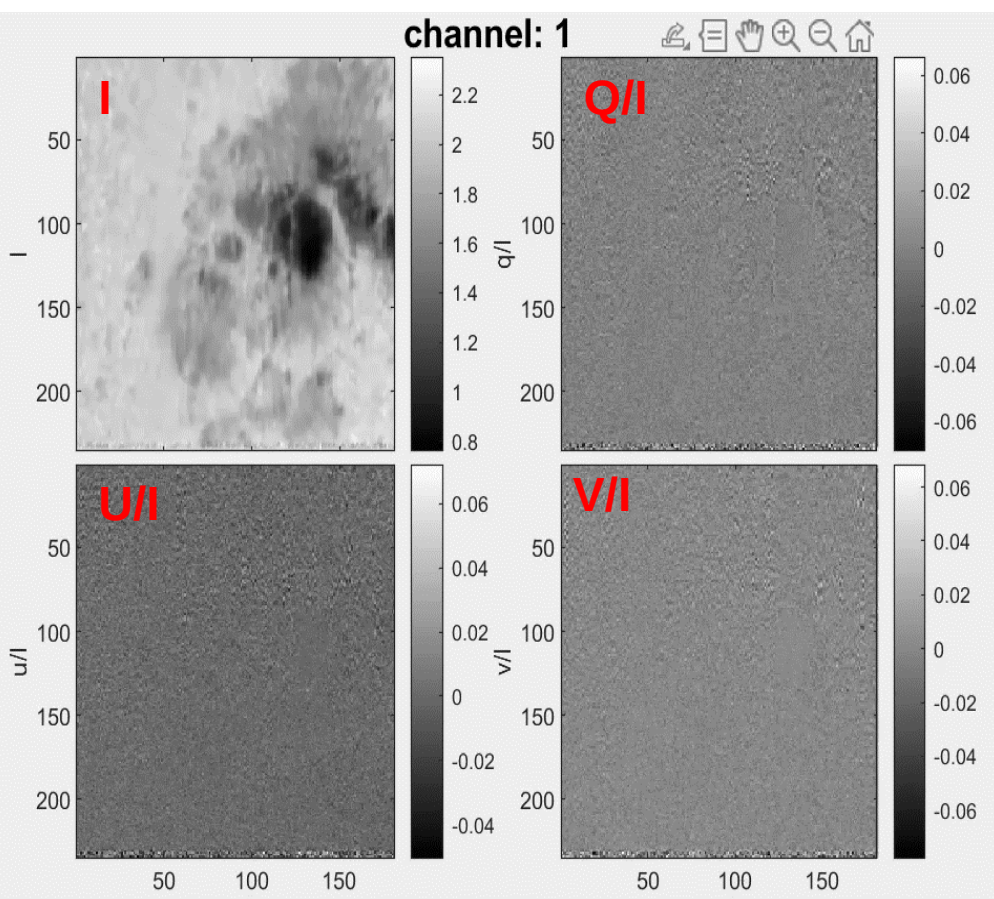


Stokes parameters maps

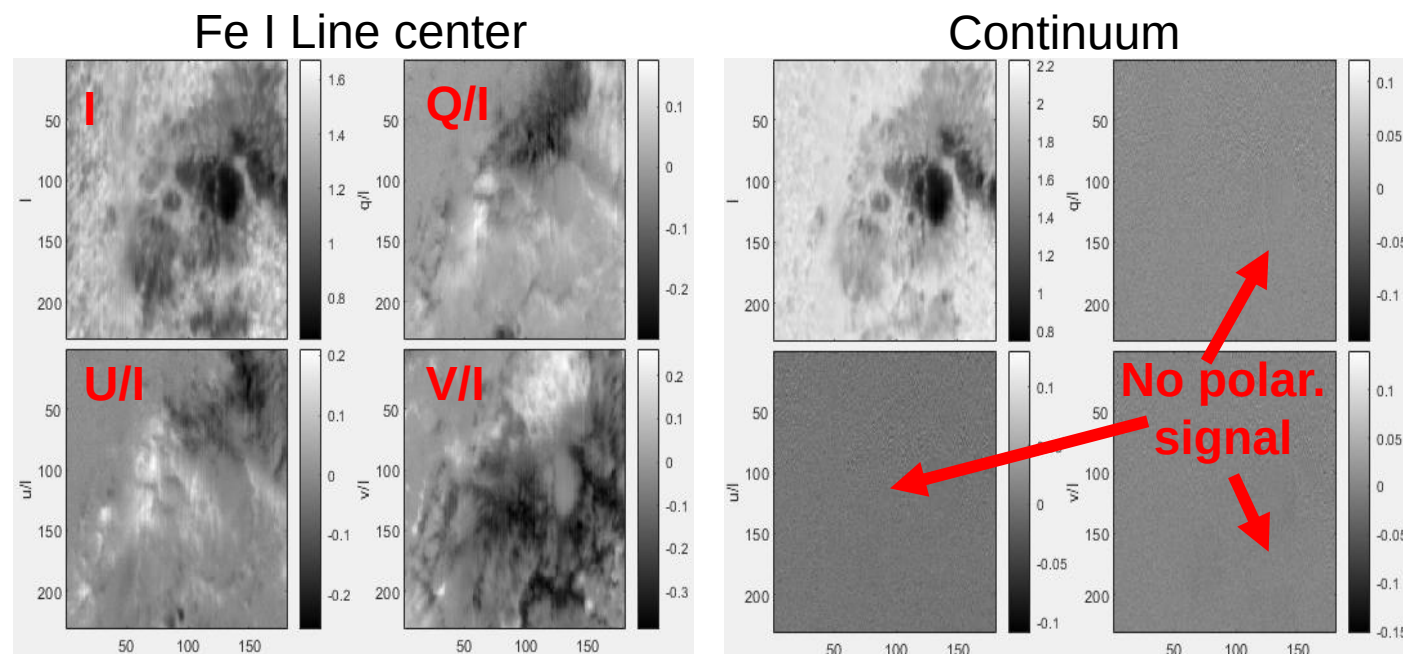
Stokes map datacube

- 256 λ channels after 2x rebinning
- 25mÅ /pixel spectral resolution

- **Complete polarization signal now routinely measured**
 - 4D data array of 4 Stokes parameter (x, y, λ , S).
 - User-friendly software in development.



NOAA 14100 ; 29/05/2025 10:30-10:50 UT

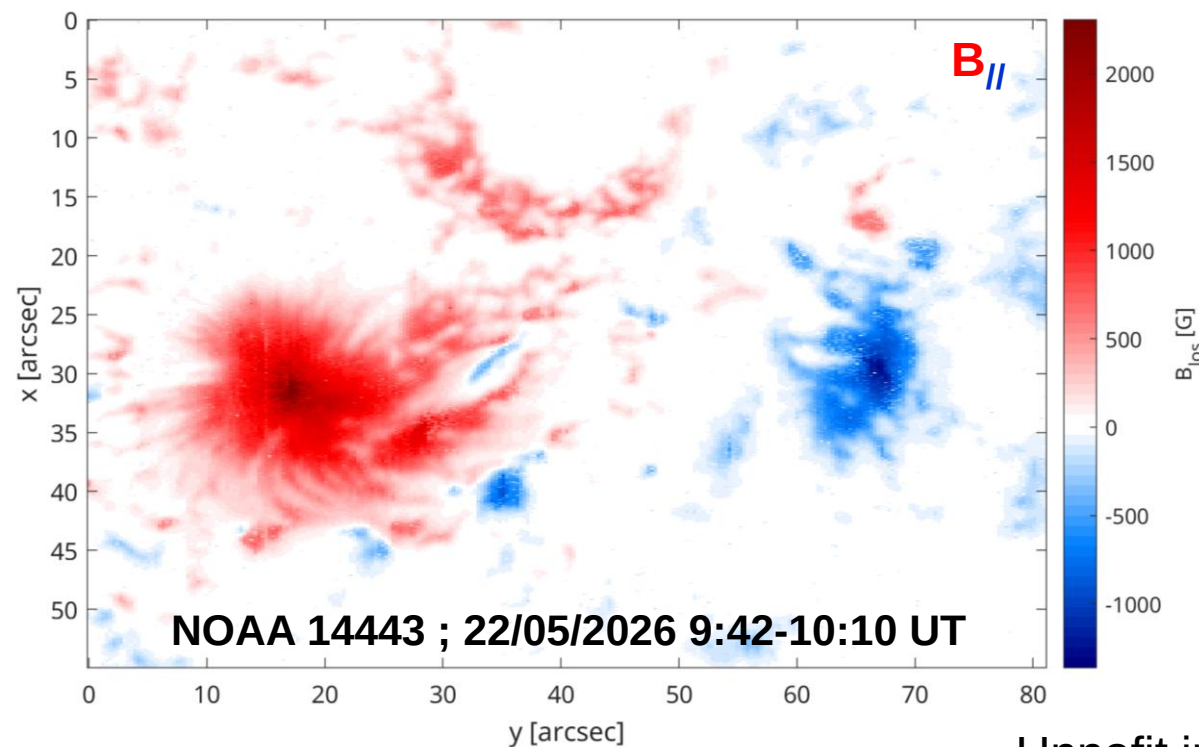
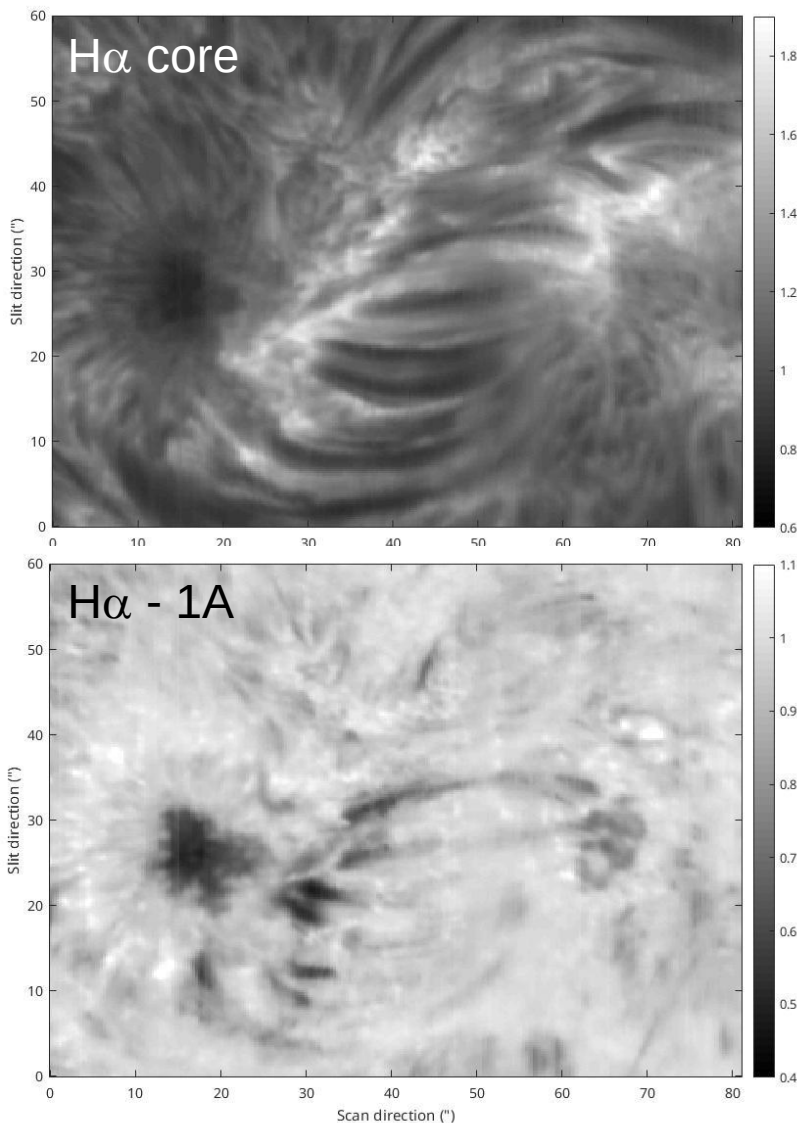


SEA XVII - THEMIS - Pariat

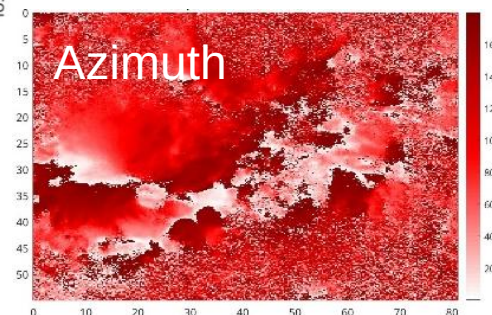
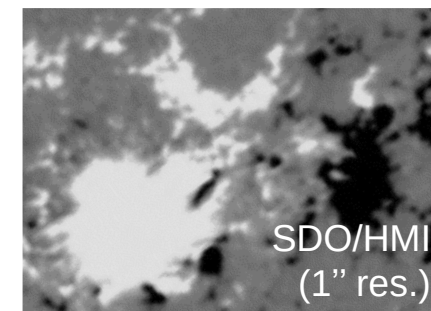
Vector (B_x , B_y , B_z) magnetic field maps production

- **New pipeline to produce vector B maps**

- **Spatial resolution $< 0.5''$** : ~400 km res. on the Sun (along scan dir.)
 - ~Hinode/SOT; ~x4 better than HMI/SDO
- UNNOFIT & PyMilne magnetic inversions available (Bommier et al. 07, de la Cruz Rodriguez 19)
- **From observation to vector maps in ~1hr**



SEA XVII - THEMIS - Pariat



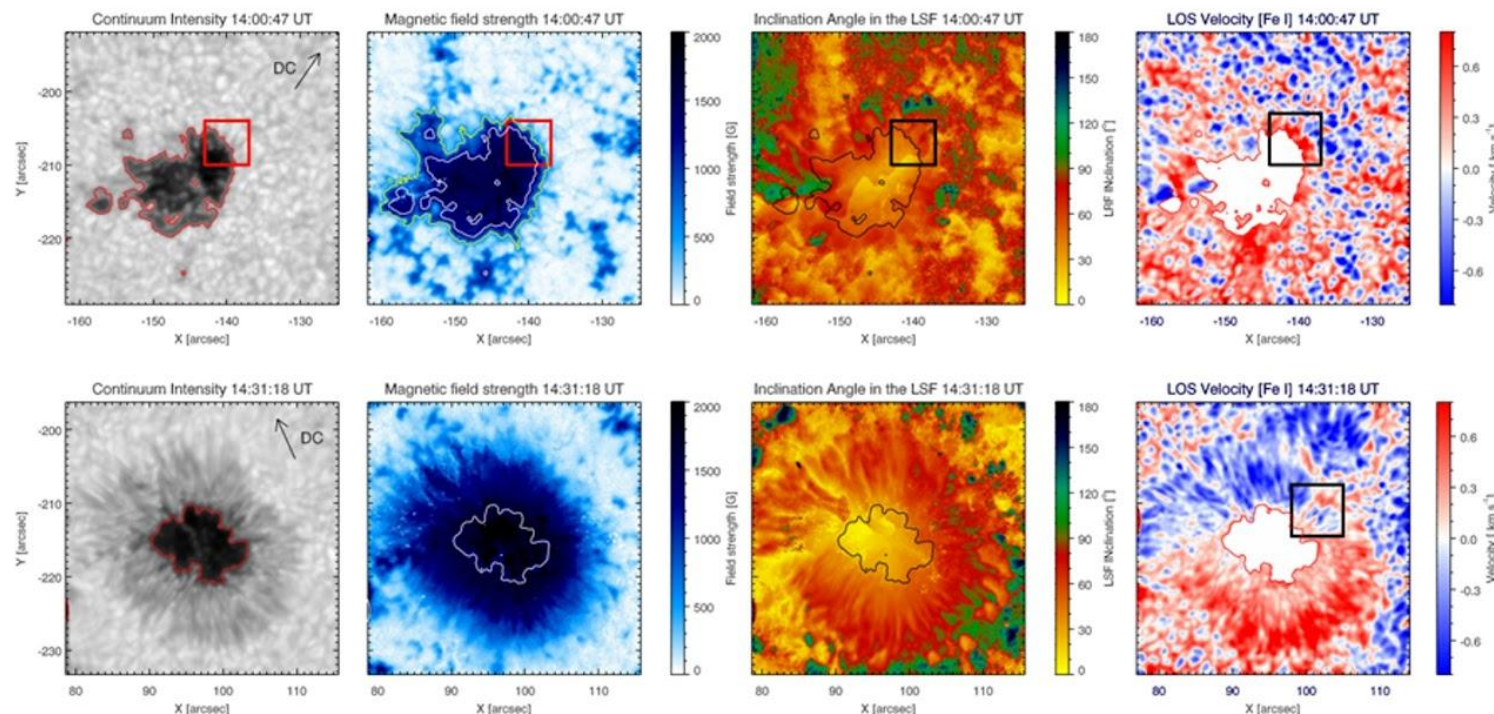
Unnofit inverted vector B map

Upcoming : IBIS 2.0 @ THEMIS



Interferometric Bldimensional Spectrometer (IBIS)

- **Spectro-imager** (x, y, λ) : dual Fabry-Perot & interference filters
- 200 000 spectral resolution
- short exposure times & polarimetric mode



- 2003-2019: IBIS running at Dunn solar tower (DST)
- Upgraded version, IBIS 2.0 looking for suitable telescope since 2019
- TAO performance attractive for IBIS 2.0
- THEMIS has no equivalent instrumental mode
- ➔ **Memorandum of Understanding signed between INAF and CNRS in winter 2024-2025 for the installation of IBIS 2.0 as a guest instrument on THEMIS**

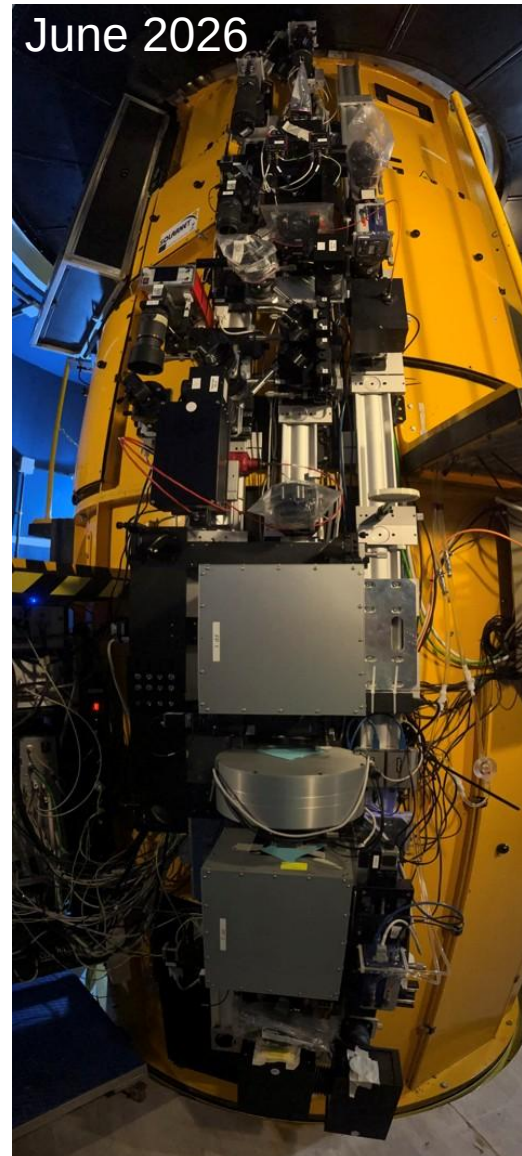
Intensity, magnetic field strength, field inclination angle, and LOS velocities on 2012 May 28 (14:00-14:30 UT): before (top) and after (bottom) penumbra formation. SIR inversion of the Stokes profiles of the Fe I 630.25 nm line acquired by IBIS . (Murabito et al. 16)

Upcoming : IBIS 2.0 to THEMIS

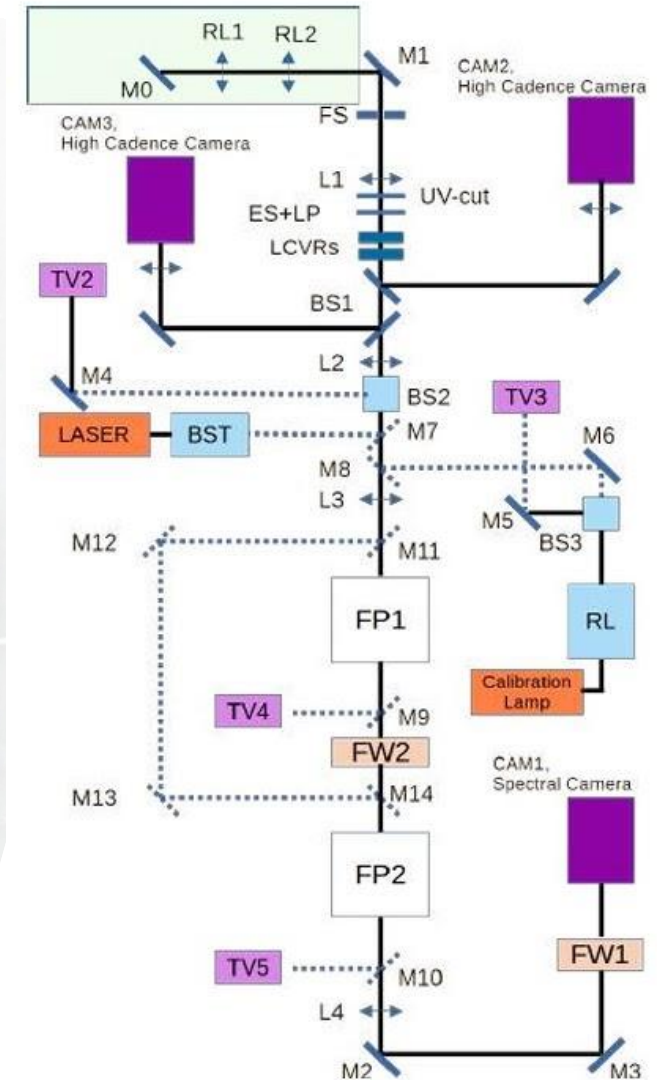
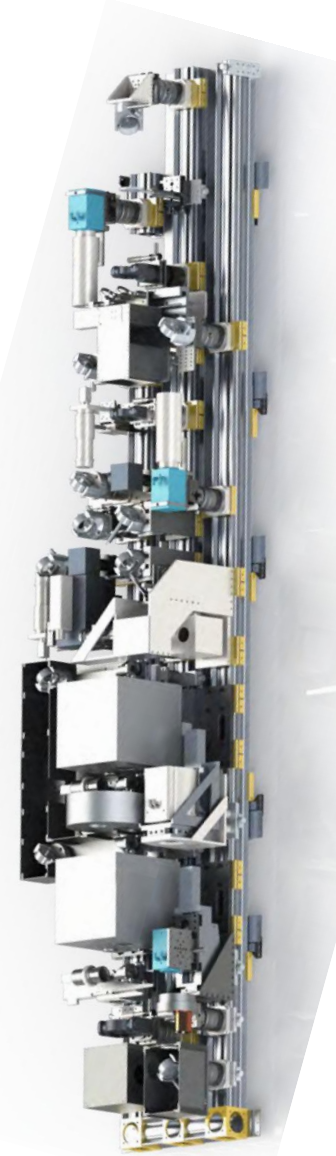


- November 2025: preparatory installation of optical bench
- Summer 2026 : IBIS 2.0 installation & start of commissioning

- **IBIS2.0 is an outstanding synergic complement of THEMIS long slit spectrograph**
- **Foster & renew French-Italian scientific collaboration in high-resolution solar physics, beneficial at large for EU solar physics (e.g. EST project)**



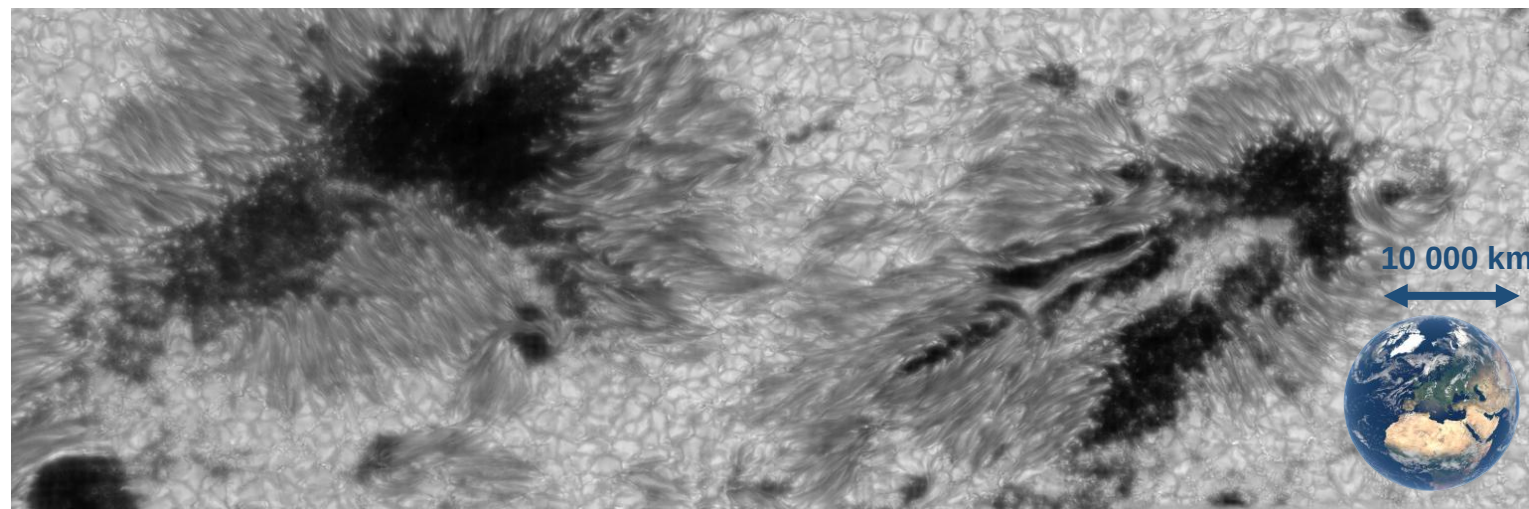
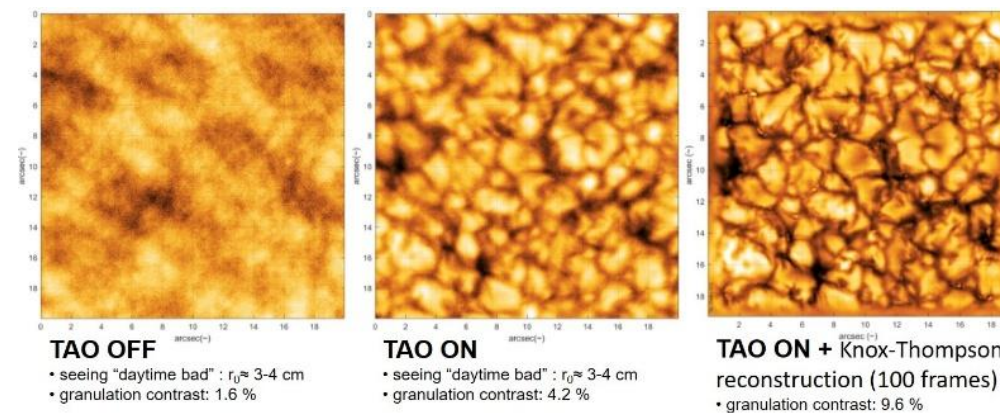
SEA XVII - THEMIS - Pariat



Ermolli et al. 2024

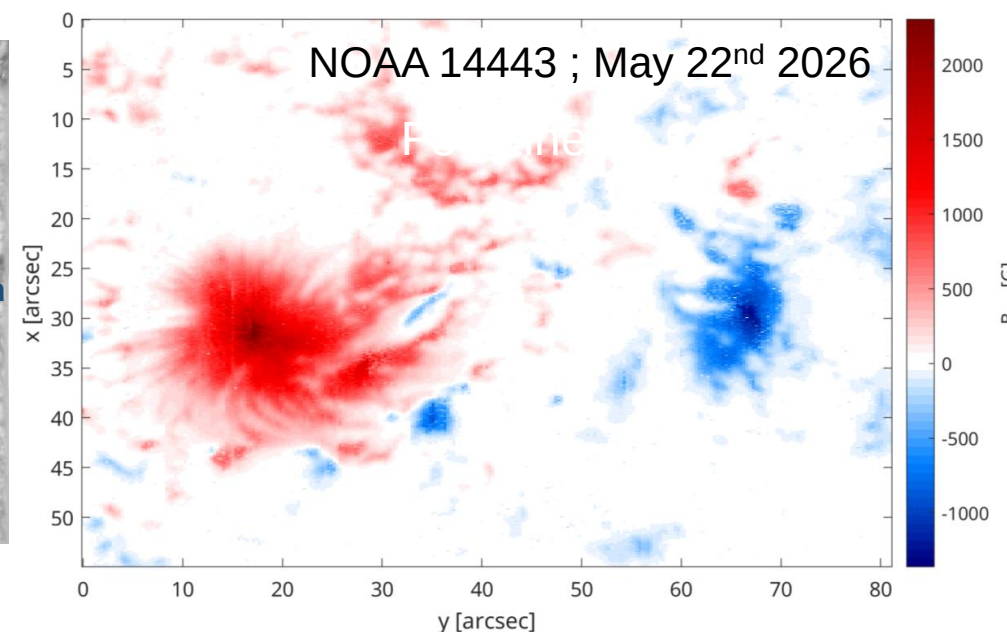
Takeaways

- **THEMIS is presently a competitive telescope with unprecedented capacities**
 - THEMIS is a real challenger in the 1m class
 - Installation of the IBIS 2.0 will trigger a larger interest.
 - Growth of staff (PhD, Postdoc, operator) thanks to key project: JET2SB (projet ANR-25-CE31-741), ESA-SWESNET
- **Open data policy** (although not easily accessible yet)
 - **Sample datasets available upon request (soon directly)**



NOAA 13354 ; June 28th 2023

Scaled size of Earth



Final remarks

- New outreach tools
 - THEMIS website; Instagram account; ...
- **Reminder: 20-25% of THEMIS observation time dedicated to Spanish-laboratory-based PIs**

THEMIS Solar Telescope

The "Télescope Héliographique pour l'Étude du Magnétisme et des Instabilités Solaires" (THEMIS) of CNRS-INSU is a 1-meter-class optical solar telescope, primarily dedicated to studying solar magnetism and the dynamical processes within the Sun's atmosphere (such as sunspots and solar flares). THEMIS can also perform observation of near-Sun objects such as Mercury and comets.

THEMIS is located at the Teide Observatory of IAC, with a base office in La Laguna, in Tenerife, Canary Islands, Spain.

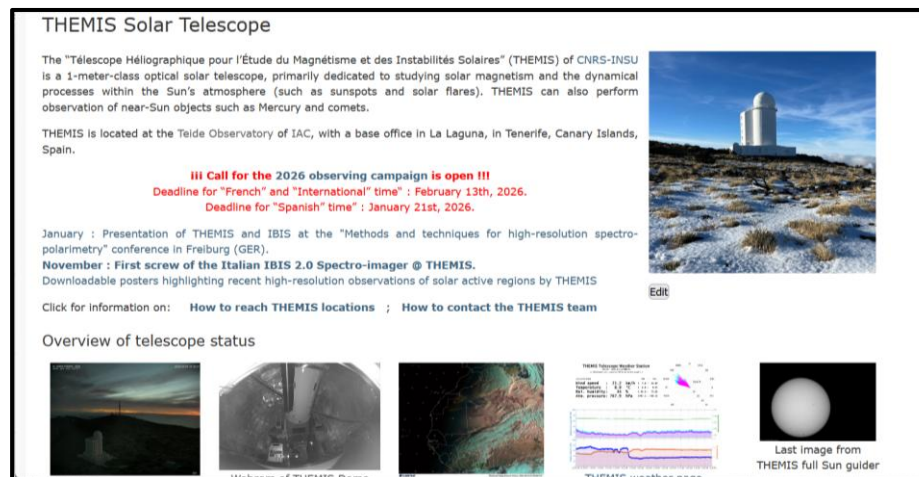
!!! Call for the 2026 observing campaign is open !!!
Deadline for "French" and "International" time : February 13th, 2026.
Deadline for "Spanish" time : January 21st, 2026.

January : Presentation of THEMIS and IBIS at the "Methods and techniques for high-resolution spectro-polarimetry" conference in Freiburg (GER).
November : First screw of the Italian IBIS 2.0 Spectro-imager @ THEMIS.

Downloadable posters highlighting recent high-resolution observations of solar active regions by THEMIS

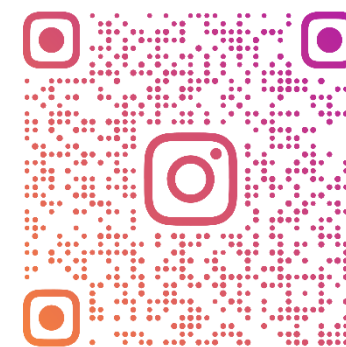
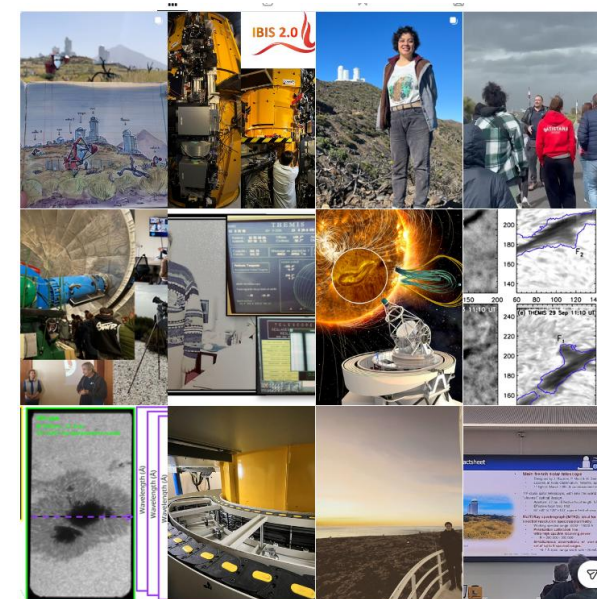
Click for information on: [How to reach THEMIS locations](#) ; [How to contact the THEMIS team](#)

Overview of telescope status



<https://www.themis.iac.es>

- THEMIS is highly open to all scientists based in Spanish lab.
- The local THEMIS team is dedicated to assist anyone in performing observations with THEMIS
- Observation at THEMIS is not reserved to an elite of high-resolution spectro-polarimetry expert !
- **Young Spanish researchers are highly welcomed to discover/run/follow ground-based solar observations campaigns of THEMIS**
- **Observation calls usually opens in December**



THEMIS_SOLAR